Combined Sewer Overflows in the Milwaukee Metropolitan Sewerage District Conveyance and Treatment System

Eric Loucks[1], David Watkins[2], Theresa Culver[3]

Background

Many older cities across the United States rely on combined sewers to convey both stormwater runoff and sanitary sewage. Combined sewer overflows (CSOs), containing untreated sewage, occur during extreme wet weather, when the capacity of these combined sewer systems is exceeded. Across the U.S., CSOs pose a serious threat to water quality in thousands of lake, river, and coastal ecosystems. In addition to harming the natural environment, they may be a threat to human health and have adverse economic consequences (e.g., beach closings, reduced aesthetics, tourism impacts) (U.S. EPA, 2011).

Several large cities in the United States, including Boston, Chicago, and Milwaukee, have addressed the problem of CSOs by constructing large underground storage systems. In Milwaukee, Wisconsin, a large "tunnel" system has been constructed to contain up to 405 million gallons (54 million ft^3 or 1.54 million m^3) of wastewater and stormwater runoff to reduce CSOs discharging to Lake Michigan. In addition to this tunnel system, the Milwaukee Metropolitan Sewerage District (MMSD) operates an extensive system of sanitary sewers to collect and convey wastewater originated by local sewer systems in a 420 mi^2 service area. Local systems are operated and maintained by municipalities within the District and those contracted with MMSD. Wastewater flows to the local systems are collected by the District's intercepting system, and then conveyed to MMSD's two wastewater treatment plants, Jones Island and South Shore (Shafer, 2005).

The main components of MMSD's combined sewage conveyance system are the Metropolitan Interceptor Sewer (MIS) System, the Inline Storage System (deep tunnels), and the Central Control System. The MIS is network of sanitary sewers that intercept wastewater from local sanitary and combined sewer systems within the MMSD service area. This system is divided into seven subsystems for purposes of flow monitoring analysis and system control. Flows can be diverted between the subsystems for conveyance to either the Jones Island or South Shore treatment facilities, or to the District's Inline (Deep Tunnel) Storage System, where they can be stored until the plants have available capacity for treatment.

[1] Senior Engineer, CDM Smith, 12357 Riata Trace Parkway, Austin TX 78727. E-mail: LoucksED@cdmsmith.com.
[2] Professor, Department of Civil and Environmental Engineering, Michigan Technological University, Houghton, MI 49931.
[3] Associate Professor, Department of Civil Engineering, P.O. Box 400742, The University of Virginia, Charlottesville, VA 22904.

The Deep Tunnel Storage System, shown in Figure 1, consists of 19.4 miles of tunnels 300 feet below ground that temporarily stores peak wastewater flows that exceed treatment plant or MIS capacities. The deep tunnel system can hold up to 405 million gallons of flow and was designed to eliminate overflows from the separated sewer area and to greatly reduce overflows in the combined sewer area. When the system became fully operational in 1994, it substantially reduced the number of annual average overflows from about 50 down to two or three.

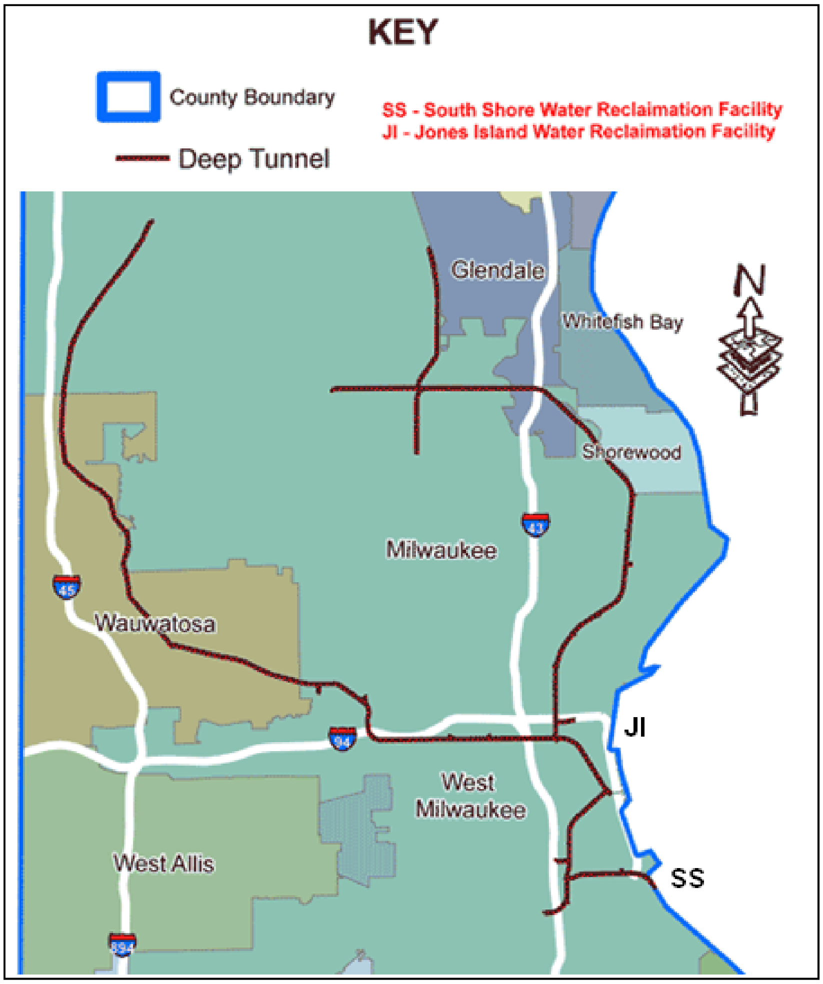

Figure 1. MMSD's Deep Tunnel (In-line Storage System) (Used with permission: http://v3.mmsd.com/deeptunnellocation.aspx)

At the Central Control System, flows are monitored using continuous and intermittent monitors. Continuous monitors are permanently installed in more than 300 locations and use telephone lines and a wireless communication system to transmit data back to the Central Control System. Intermittent monitors are temporarily installed and rely on field crews to retrieve the data. Along with monitoring flow data, the Central Control System allows remote operation of the conveyance system, with the goal ensuring that treatment plant and conveyance capacity is utilized in the most efficient manner.

Figure 2 illustrates operation of the combined wastewater and stormwater conveyance and treatment system during wet weather and extreme wet weather events. In the separated sewer area, storm sewer flow is discharged directly to local waterways through local storm sewers, while sanitary sewage normally travels into local sanitary sewers, the MIS, and treatment plants. In extreme wet weather events, when local sanitary sewers or MIS cannot handle excessive inflow and infiltration[4] into the sanitary sewer system, excess flow is either bypassed (overflows) to nearby waterways, or it may be diverted to the deep tunnel, where it is stored until the plants have capacity to treat it.

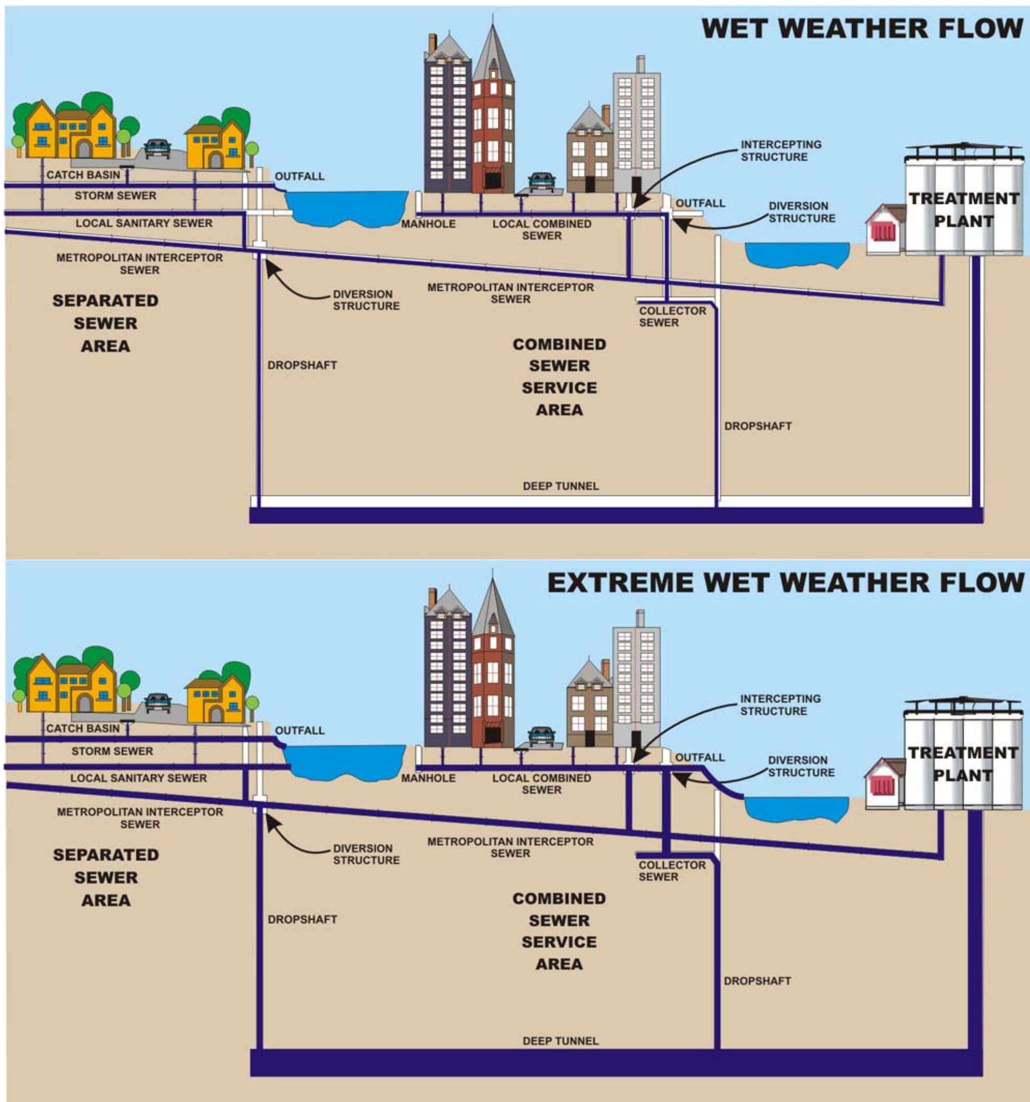

Figure 2. Operation of the combined sanitary and stormwater conveyance and treatment system under (a) wet weather conditions and (b) extreme wet weather conditions (Used with permission: http://v3.mmsd.com/deeptunnelhowitworks.aspx)

[4] Inflow and infiltration (I&I) in sanitary sewer systems is a national problem. It is the result of poor construction, aging systems needing repair, and/or illicit stormwater connections (Shafer 2005).

In the combined sewer area, sanitary sewage travels into local combined sewers, where it mixes with stormwater from runoff. Flow from the combined sewers empties into the MIS to be conveyed to the plants for treatment, and excess flow is bypassed to nearby waterways at combined sewer outfalls. If the plants are not able to handle excessive infiltration and inflow, excess flow is diverted to the deep tunnel. If the deep tunnel is filled, excess flow is discharged to local waterways.

Description of the MACRO Model

The MACRO model was developed to evaluate the operation of the MMSD conveyance and storage system (Reference). Written in the Fortran programming language, MACRO is a routing model that simulates movement of flow through the MIS subsystems to the wastewater treatment plants (South Shore and Jones Island), the Inline Storage System, and system overflow outfalls (separate and combined sewer overflows). Flow continuity is maintained throughout each (hourly) time step of the simulation, and the volume of separate sewage and combined sewage present in the ISS is tracked. A schematic of the MACRO network system is shown in Figure 3.

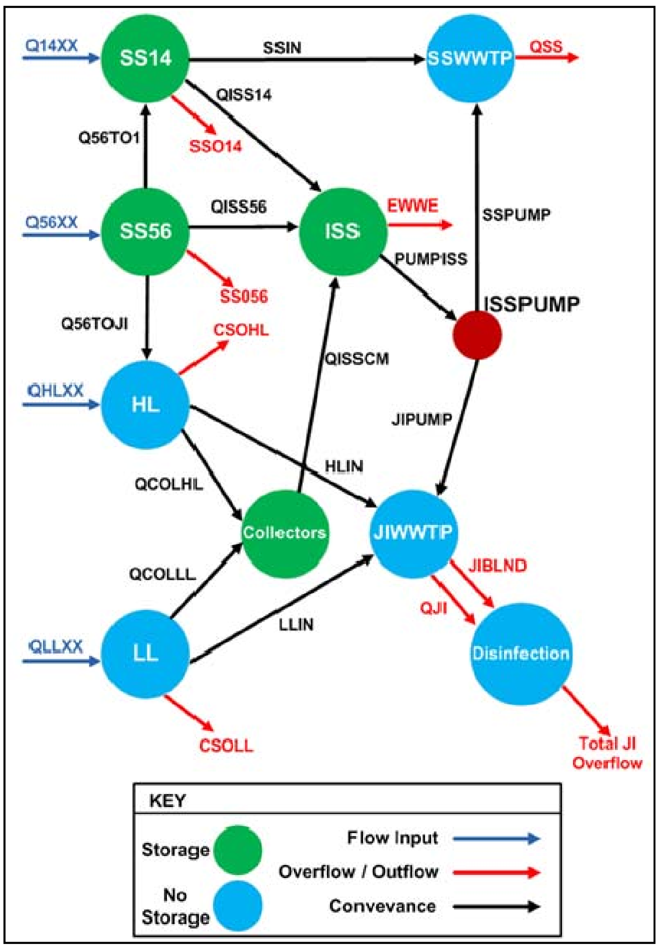

Figure 3. MACRO system schematic, showing the main MIS subsystems, the Inline Storage System (ISS), and the wastewater treatment plans (SSWWTP and JIWWTP) (adapted from CDM, 2005)

The MACRO model also simulates blending at the Jones Island plant. Blending is a process in which a certain portion (as allowed by permit) of the total plant inflow bypasses primary and secondary treatment and is blended with the treated flow prior to chlorination and discharge. This process, shown in Figure 4, effectively increases the capacity of the treatment plant, which otherwise would be limited by the secondary treatment capacity.

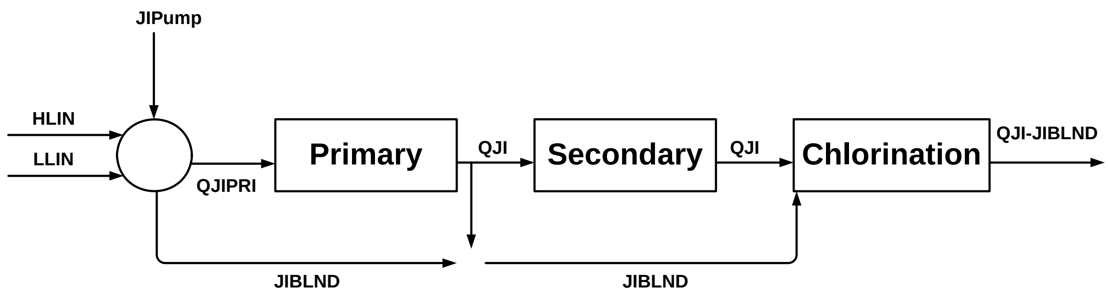

Figure 4. Blending at Jones Island Wastewater Treatment Plant (JIWWTP) (adapted from CDM, 2005)

There are three input files needed to run MACRO (Figure 5). The Command file contains the parameters controlling the simulation, including input and output file names, system capacities (limits), the start and end dates of the simulation, and various user options. This is the file that users can change to test different system alternatives (e.g., expanding the in-line storage capacity or treatment plant capacities). The HSPF Input file contains hourly runoff values for the system as computed by the Hydrologic Simulation Program-Fortran (Crawford and Linsley 1966, Bicknell et al. 1997) using precipitation and temperature data for the period 1940-2004. The VRSSI file (“VRSSIHINDCAST.INP”) contains daily or hourly values of storage to be reserved for separate sewage inflow to the Inline Storage System. These values have been calculated as the best values, dynamically adjusted, to minimize SSOs over the historical record. As an alternative to this “perfect hindsight,” the user may specify a dummy VRSSI file and a (constant) minimum volume of storage to reserve for separate sewage inflow, VRSSImin, for more realistic simulation results. The value of VRSSImin may be adjusted from 0 to the total volume of the tunnel. MMSD has slowly increased it over the years from 40 million gallons to the current 250 million gallons (5.35 to 33.42 million ft^3).

The file VRSSIHINDCAST.INP contains perfect hindcasts of the best value to use in each historical storm. Perhaps a poorer set of values should be used, because these are difficult to improve upon. The minimum VRSSI (on line 14) will have some effect though. Perhaps students could use a "dummy" VRSSI file (provided). Then VRSSI is controlled only by the minimum value on line 14.

MACRO generates four output files (Figure 5). The Report file (***.RPT) lists summary data for the entire simulation run, including annual ISS and CSO/SSO summaries. The Event Summary file (***.DAT) provides output from each ISS event in the simulation. The Detailed Output file (***.OUT) lists detailed hourly output. Finally, the Remote Storage summary provides summary data for remote storage. Only the Report and Summary files will be used in this exercise.

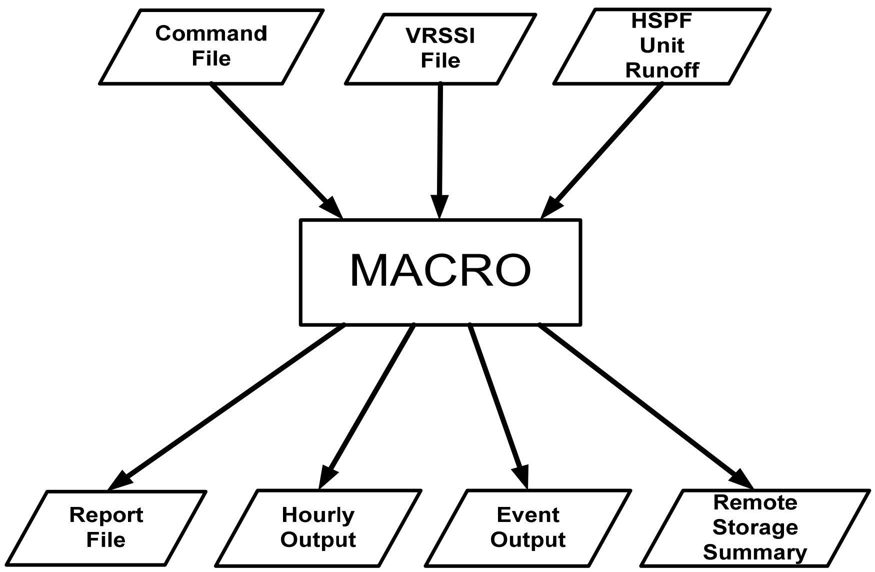

Figure 5. MACRO model input and output files (adapted from CDM, 2005)

MACRO is used to evaluate various structural and operational alternatives to prevent SSOs and CSOs. There are three basic ways to prevent overflows: (1) Operate the treatment and storage in the system more efficiently; (2) Increase treatment/blending capacity at the treatment plants (including flow capacity to the plants, if that is a limiting factor); and (3) Increase storage capacity in the ISS. Operating decisions include the following:

- Adjusting VRSSI dynamically, or specifying VRSSImin
- Increasing blending (requires a permit; also need to increase chlorination limit)
- Diverting more/less to South Shore WWTP

Capital investment options include the following:

- Increase tunnel (ISS) volume
- Increase pumping capacities from ISS to WWTPs
- Increase siphon capacity at JIWWTP
- Increase treatment capacity at JIWWTP

Assignment

Using the MACRO model provided, evaluate some of the structural and operational alternatives to further reduce SSOs and CSOs, assuming you have a limited capital investment budget of $250 million. The problem can be stated as:

Minimize: SSOs, CSOs, or some combination of the two

Subject to:

1. ISS storage capacity
2. Pumping capacities from ISS to WWTPs
3. Treatment capacities at WWTPs
4. Siphon capacity at JIWWTP
5. Budget limit for capital investment ($250 million)

Consider the capital investment and operational alternatives listed in Table 1.

Table 1. Capital investment and operational options for reducing SSOs and CSOs.

Measure	**Cost**	**Input notes**
Increase tunnel (ISS) volume	$15/ft^3	Line 13 of Command file
Adjust VRSSImin	None	Line 14
Increase pumping capacities from ISS to WWTPs	45 cfs pump costs $5 million	Lines 20 and 22 (Jones Island and South Shore, respectively)
Increase siphon capacity at JIWWTP	Each siphon costs $12 million to upgrade to 400 cfs	Lines 33 and 34
Increase treatment capacity at JIWWTP*	$1 million/cfs	Need to change values on lines 36 and 38, and corresponding limit on line 37

* Blending at JIWWTP is limited by permit to 94 cfs.

Evaluate alternative designs by running the MACRO model with the 1940-2004 hydrologic record. To modify input parameters for the model, you will change the Command file MITCHELL.CMM. Use the mitfld.PLT and VRSSI_zero.inp files as the other input files. Select the metric(s) by which you will compare the various alternatives.

One additional suggestion for running MACRO is to turn off “treatment plant averaging” by setting line 10 of the Command file to "1". MACRO runs about 20 times faster if you turn off the treatment plant averaging, as there is a lot of overhead tracking the average inflows over the past 24, 48, 72, ... and 720 hours. Other lines of the Command file not mentioned here should remain unchanged. Please see the MACRO User's Manual (CDM, 2005) for a complete description of the model and input and output files. A sample input file is also provided in the Instructor's Notes (Appendix).

References

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Donigian, A.S., Jr., and Johanson, R.C. (1997). *Hydrological Simulation Program--Fortran, User's manual for version 11*, U.S. Environmental Protection Agency, National Exposure Research Laboratory, Athens, Ga., EPA/600/R-97/080, 755 pp.

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Crawford, H.H., and Linsley, R.K. (1966). Digital Simulation in Hydrology: Stanford Watershed Model IV, Technical Report No. 39, Dept. of Civil Engineering, Stanford University, Stanford, CA, 210 pp.

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U.S. Environmental Protection Agency (2011). Combined Sewer Overflows. http://cfpub.epa.gov/npdes/home.cfm?program_id=5. Accessed 2 May 2011.